Small-Scale Morphology and Boundary Layer Processes: Measurement And Modeling

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Award #: N00014-97-0790

LONG-TERM GOALS

The main goal of the research project is to contribute to a better understanding of the basic mechanisms controlling sediment transport in the nearshore regions. In particular the structure of the flow in the bottom boundary layer is of interest along with its interaction with sediment dynamics and bottom morphology.

OBJECTIVES

We want to look at the dynamics of the coherent vortex structures which are generated at the bottom of sea waves by 1) the instability of the laminar boundary layer and the development of turbulence, 2) the nonlinear interaction of the oscillatory boundary layer with a wavy bed of small amplitude and with a sloping bottom and 3) the separation of the boundary layer at the crests of 2-D ripples of large amplitude.
The flow will then be used to study sediment dynamics and the processes which lead to the formation of small and medium scale bedforms.

APPROACH

The investigation is based on: analytical approaches; numerical simulations of momentum (Navier-Stokes) and continuity equations and the analysis of field data. Analytical solutions describing the flow field generated by a propagating wave close to the sea bottom are solved to understand certain field measurements and to study how the flow in the bottom boundary layer affects some large scale morphodynamic phenomena. The numerical codes consider the full 3-D problem and simulate large coherent vortex structures and turbulence. Field data are used to test the theoretical findings.

WORK COMPLETED

a) The code to study transition from the laminar to the turbulent regime in the boundary layer at the bottom of sea waves, which was completed and tested during the first year of the project, has been used to investigate turbulence structure at moderate values of the Reynolds number.

b) The code to study the separated oscillatory flow close to a rippled sea bed has been validated comparing the numerical results with the analytical findings described in Hara & Mei (1990). Moreover some results have been obtained for relevant values of the parameters of the problem.

c) The study of the steady flow generated by a progressive wave propagating on a sloping beach has been started. The steady velocity field has been determined both in the bottom boundary layer and in the core region using the creeping flow approximation i.e. for small values of the ratio between the wave amplitude a and the thickness δ of the bottom boundary layer. Moreover a numerical code for arbitrary values of a/δ has been developed.

d) Mechanism generating bottom forms in the nearshore region which are periodic in the longshore direction has been studied. The obtained results have been compared with field data.

e) The co-operation between the Naval Postgraduate School and Genoa University has been continued and in particular Prof. Blondeaux and Dr. Vittori have visited N.P.S. for two months (July and August 1998). During this period a seminar on turbulence structure in oscillating boundary layers has been given. Moreover an active co-operation between Blondeaux, Vittori and Stanton, Thornton has been started on topic (c). The personnel exchanges from the beginning of the project can be summarized as follows:

Name	Position	From	To	Starting date	Duration of the stay
Dr. E. Foti	Senior Researcher & Temporary Professor	University of Catania Italy	Naval Postgraduate School USA	≈ 15 August 1997	5 months
Dr. G. Vittori	Senior Researcher & Temporary Professor	University of Genova Italy	Naval Postgraduate School USA	≈ 1 July 1998	2 months
Prof. P. Blondeaux	Full Professor	University of Genova Italy	Naval Postgraduate School USA	≈ 1 July 1998	2 months

RESULTS

a) The direct simulations of the oscillatory flow close to a flat but imperfect wall, for moderate values of the Reynolds number, have allowed to investigate the characteristics of turbulence in the intermittently turbulent regime. In this flow regime perturbations of the Stokes flow start to appear towards the end of the accelerating phases of the cycle but reach their maximum intensity at the beginning of the decelerating parts. At the end of the decelerating phases, the disturbances rapidly decay and attain low level of energy. Figure 1 shows that during flow acceleration large vortex structures are generated. As the external flow decelerates, the coherent vortices break and originates much smaller vortex structures which then decay because of viscous affects. In this flow regime the wall shear stress turns out to be maximum at the end of the accelerating and early decelerating phases and it is practically in phase with the irrotational velocity component. However a large peak is present which might be the cause of the behaviour of the sediment pick processes observed by Ribberink and Al-Salem (1994).

b) The three dimensional flow caused by an oscillating uniform pressure gradient close to a rippled bed has been investigated by the numerical simulation of Navier-Stokes equations. Because of the high computational costs, the flow has been computed only for moderate values of the Reynolds number. In particular values of the parameters have been considered close to those investigated theoretically by Hara and Mei (1990) who considered weak oscillations over ripples of finite slope (case i) and moderate oscillations over ripples characterized by very gently slope (case ii). However in the former case larger amplitudes of fluid oscillations have been considered and in the latter case larger ripple height have been studied such that nonlinear effects are significant. The obtained results have shown that flow separation has a strong influence on the growth of the three-dimensional perturbations of the basic two-dimensional flow and that the unstable regions predicted by Hara and Mei (1990) widen when a separated flow is considered.

c) Because of nonlinear effects and self-interaction, the wave motion induces steady streamings and a net flux of water. Although the steady velocity components are often weak when compared with the fluctuating ones, the former play a significant role in many transport phenomena and in particular they have a strong influence on sediment transport because of their persistence. Most of the investigations of the problem were carried out considering horizontal bottoms and the theoretical and experimental results dealing with mass transport velocities over sloping bottoms are very scarce. Some experiments were carried out by Bijker et al. (1974) and by Wang et al. (1982). In the present research an attempt has been performed to predict the behaviour of the steady velocity component for a partially reflected wave propagating on a gently sloping bottom. Because

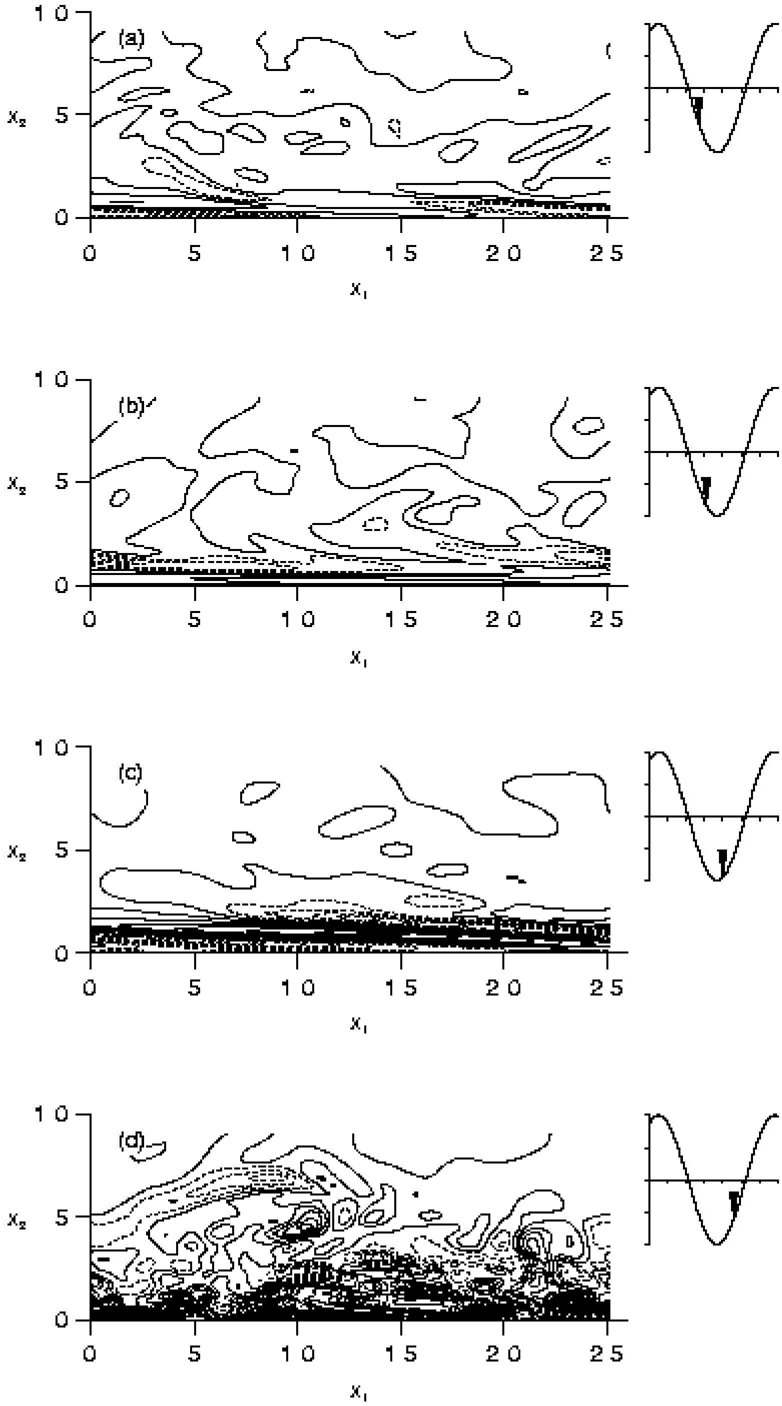

Figure 1 Instantaneous snapshots of the spanwise component of vorticity in a vertical plane for a Reynolds number in the intermittently turbulent regime.

large values of the Reynolds number have been considered, the flow domain has been split in a bottom boundary layer and in an outer region up to the free surface. The water depth has been assumed to be much smaller than the length of the waves and the shallow water approximation has been used. Moreover small wave amplitudes have been considered. First the analysis has been developed by assuming the regime in the bottom boundary layer to be laminar and then (during the stay of Blondeaux and Vittori at N.P.S.) the theory has been extended (in co-operation with Thornton and Stanton) at the turbulent regime which is more significant when dealing with field cases. The procedures to obtain quantitative results are now ready.

A coherent Acoustic Sediment Probe (CASP) was deployed from an instrumented sled during some nearshore experiments at Duck, North Carolina, in October 1994 and 1997. The CASP measured acoustic backscatter profiles and three component velocity vectors.

The stresses measured near the bed in a gravity oriented vertical reference system are associated with both the turbulent Reynolds' stresses and a wave stress due the vertical velocity induced by the horizontal wave velocity acting on the sloping bottom being correlated with the horizontal velocity. The wave stress is largest at the bed and decreases towards the surface and can be larger than the turbulent Reynolds' stresses. A joint research between N.P.S. and Genoa University has been developed to investigate theoretically whether an appropriate rotation of the co-ordinate system exists such that the time correlation of the wave velocity components vanishes. The wave has been characterised by a small amplitude and by a large wavelength in such a way to linearize the problem and to use the shallow water approximation. An explicit relation providing the orientation of the co-ordinate system has been obtained and the test of the analytical solution has been started.

d) The morphology of the beach face and of the sea bed in the nearshore region exhibits a variety of longshore and offshore structures with a broad spectrum of length scales ranging from few centimetres to some kilometres (Allen, 1984). Surprisingly often, periodic longshore patterns (beach cusps, giant cusps, crescentic forms, rhythmic topographies) are detected (Komar, 1971). Some of these bedforms appear to be restricted to the beach face (swash cusps) while others extend through the surf-zone (surf-zone cusps) and further offshore, sometimes without involving the coastline configuration (crescentic forms and rhythmic topographies). The main objective of the research has been to discuss a new morphologic instability mechanism which applies to regions far away from the swash region. The basic mechanism is that the incoming wave interacts with a small bottom perturbation (periodic in the longshore direction) and produces a synchronous edge wave. This wave subsequently interacts with the incoming wave and leads to the generation of steady currents. The latter induce a net sediment transport, the convergence pattern of which is in phase with the bedforms. Hence there is a positive feedback between the water motion and the erodible bottom which gives rise to an exponential growth of both the free surface and bottom perturbations.

The theoretical results have been compared with field observations to illustrate the potential relevance of the instability mechanism.

IMPACT/APPLICATIONS

RELATED PROJECTS

- "Sediment Transport Modeling in Marine Coastal Environments" research project of European Union. MAS3-CT97-0115 SEDMOC.
- "Prediction of aggregate-scale coastal evolution" research project of European Union. MAS3-CT95-0002 PACE.

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